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*Article*

# Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector

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**Abstract:** This paper presents a conceptual framework aimed at implementing sustainability principles in the building industry. The proposed framework based on the sustainable triple bottom line principle, includes resource conservation, cost efficiency and design for human adaptation. Following a thorough literature review, each principle involving strategies and methods to be applied during the life cycle of building projects is explained and a few case studies are presented for clarity on the methods. The framework will allow design teams to have an appropriate balance between economic, social and environmental issues, changing the way construction practitioners think about the information they use when assessing building projects, thereby facilitating the sustainability of building industry.

**Keywords:** sustainable building; conceptual framework; resource conservation; cost efficiency; human adaptation

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## 1. Introduction

The building industry is a vital element of any economy but has a significant impact on the environment. By virtue of its size, construction is one of the largest users of energy, material resources, and water, and it is a formidable polluter. In response to these impacts, there is growing consensus among organizations committed to environmental performance targets that appropriate strategies and actions are needed to make building activities more sustainable [1–3]. With respect to such significant influence of the building industry, the sustainable building approach has a high potential to make a valuable contribution to sustainable development. Sustainability is a broad and complex concept, which has grown to be one of the major issues in the building industry. The idea of sustainability involves enhancing the quality of life, thus allowing people to live in a healthy environment, with improved social, economic and environmental conditions [4]. A sustainable project is designed, built, renovated, operated or reused in an ecological and resource efficient manner [5]. It should meet a number of certain objectives: resource and energy efficiency; CO2 and GHG emissions reduction; pollution prevention; mitigation of noise; improved indoor air quality; harmonization with the environment [6]. An ideal project should be inexpensive to build, last forever with modest maintenance, but return completely to the earth when abandoned [7].

Building industry practitioners have begun to pay attention to controlling and correcting the environmental damage due to their activities. Architects, designers, engineers and others involved in the building process have a unique opportunity to reduce environmental impact through the implementation of sustainability objectives at the design development stage of a building project. While current sustainability initiatives, strategies and processes focus on wider global aspirations and strategic objectives, they are noticeably weak in addressing micro-level (project specific level) integrated decision-making [8]. Paradoxically, it is precisely at the micro-levels that sustainability objectives have to be translated into concrete practical actions, by using a holistic approach to facilitate decision making. Although new technologies such as Building Research Establishment Environmental Assessment Method (BREEAM), Building for Environmental and Economic Sustainability (BEES), Leadership in Energy and Environmental Design (LEED) *etc*., are constantly being developed and updated to complement current practices in creating sustainable structures, the common objective is that buildings are designed to reduce the overall impact of the built environment on human health and the natural environment.

This paper therefore compliments existing research in the field of sustainability by reporting the development a conceptual framework for implementing sustainability objectives at the project-specific level in the building industry from a life-cycle perspective. The framework contributes to the industry and sustainability research by demonstrating the scale of the issues involved, beginning with an assessment of the environmental challenges the industry faces. It puts forward strategies and methods to mitigate the environmental impacts of construction activities, thereby facilitating the sustainability of building projects.

## 2. Sustainable Building Principles

It is estimated that by 2056, global economic activity will have increased fivefold, global population will have increased by over 50%, global energy consumption will have increased nearly threefold, and global manufacturing activity will have increased at least threefold [9,10]. Globally, the building sector is arguably one of the most resource-intensive industries. Compared with other industries, the building industry rapidly growing world energy use and the use of finite fossil fuel resources has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts—ozone layer depletion, carbon dioxide emissions, global warming, climate change [10]. Building material production consumes energy, the construction phase consumes energy, and operating a completed building consumes energy for heating, lighting, power and ventilation. In addition to energy consumption, the building industry is considered as a major contributor to environmental pollution [11–14], a major consumption of raw materials, with 3 billion tons consume annually or 40% of global use [13,15–18] and produces an enormous amount of waste [19,20]. The principal issues associated with the key sustainable building themes has been mapped out and collated in the Table 1.

**Table 1.** Sustainable building issues.

| Title | Key Theme | Principal Issues |
|---|---|---|
| **Economic sustainability** | **1.0 Maintenance of high and stable levels of local economic growth and employment**<br>1.1 Improved project delivery<br>1.2 Increased profitability & productivity | Improved productivity; Consistent profit growth; Employee satisfaction; Supplier satisfaction; Client satisfaction<br>Minimizing defects; Shorter and more predictable completion time; Lower cost projects with increased cost predictability; Delivering services that provide best value to clients<br>and focus on developing client business |
| **Environmental sustainability** | **2.0 Effective protection of the environment**<br>2.1 Avoiding pollution<br>2.2 Protecting and enhancing biodiversity<br>2.3 Transport planning | Minimizing polluting emissions; Preventing nuisance from noise and dust by good site and depot management; Waste minimization and elimination; Preventing pollution incidents and breaches of environmental requirements; Habitat creation and environmental improvement; Protection of sensitive ecosystems through good construction practices and supervision; Green transport plan for sites and business activities |
| | **3.0 Prudent use of natural resources**<br>3.1 Improved energy efficiency<br>3.2 Efficient use of resources | Energy efficient at depots and sites; Reduced energy consumption in business activities; Design for whole-life costs; Use of local supplies and materials with low embodied energy; Lean design and construction avoiding waste; Use of recycled/sustainability sourced products<br>Water and Waste minimization and management |
| **Social sustainability** | **4.0 Social progress which recognizes the needs of everyone**<br>4.1 Respect for staff<br>4.2 Working with local communities and road users<br>4.3 Partnership working | Provision of effective training and appraisals; Equitable terms and conditions; Provision of equal opportunities; Health, safety and conducive working environment; Maintaining morale and employee satisfaction; Participation in decision-making; Minimizing local nuisance and disruption; Minimizing traffic disruptions and delays; Building effective channels of communication; Contributing to the local economy through local employment and procurement; Delivering services that enhance the local environment; Building long-term relationships with clients; Building long-term relationships with local suppliers; Corporate citizenship; Delivering services that provide best value to clients and focus on developing client business |

Sustainable building approach is considered as a way for the building industry to move towards achieving sustainable development taking into account environmental, socio and economic issues, as shown in Table 1. It is also a way to portray the industry's responsibility towards protecting the environment [3,17,21,22]. The practice of sustainable building refers to various methods in the process of implementing building projects that involve less harm to the environment—*i.e.*, prevention of waste production [23], increased reuse of waste in the production of building material—*i.e.*, waste management [24,25], beneficial to the society, and profitable to the company [26–29]. Hill and Bowen [30] state that sustainable building starts at the planning stage of a building and continues throughout its life to its eventual deconstruction and recycling of resources to reduce the waste stream associated with demolition. The authors then describe sustainable building as consisting of four principles: social, economic, biophysical and technical. Amongst the published work relating to the principles of sustainable building are collated in Table 2.

**Table 2.** Principles of sustainable development.

| Authors | Proposed principles for sustainable building |
|---|---|
| Halliday [1] | *Economy:* Good project management is a vital overarching aspect in delivering sustainable projects, both in the short and long term.<br>*Using Resources Effectively:* Buildings should not use a disproportionate amount of resources, including money, energy, water, materials and land during construction, use or disposal.<br>*Supporting Communities:* Projects should clearly identify and seek to meet the real needs, requirements and aspirations of communities and stakeholders while involving them in key decisions.<br>*Creating Healthy Environments:* Projects should enhance living, leisure and work environments; and not endanger the health of the builders, users, or others, through exposure to pollutants or other toxic materials.<br>*Enhancing biodiversity:* Projects should not use materials from threatened species or environments and should seek to improve natural habitats where possible through appropriate planting and water use and avoidance of chemicals.<br>*Minimising pollution:* Projects should create minimum dependence on polluting materials, treatments, fuels, management practices, energy and transport. |
| DETR [32] | Profitability and competitiveness, customers and clients satisfaction and best value, respect and treat stakeholders fairly, enhance and protect the natural environment, and minimise impact on energy consumption and natural resources. |
| Hill and Bowen [30] | *Social pillar:* improve the quality of life, provision for social self-determination and cultural diversity, protect and promote human health through a healthy and safe working environment and *etc*.<br>*Economic pillar:* ensure financial affordability, employment creation, adopt full-cost accounting, enhance competitiveness, sustainable supply chain management.<br>*Biophysical pillar:* waste management, prudent use of the four generic construction resources (water, energy, material and land), avoid environmental pollution and *etc*.<br>*Technical pillar:* construct durable, functional, quality structure *etc*. These four principles are contained within a set of over-arching, process-oriented principles (e.g., prior impact assessment of activities). |

**Table 2.** *Cont.*

| Authors | Proposed principles for sustainable building |
|---|---|
| Miyatake [33] | Minimization of resource consumption, maximization of resources reuse, use of renewable and recyclable resources, protection of the natural environment, create a healthy and non-toxic environment, and pursue quality in creating the built environment |
| Cole and Larsson [34] | Reduction in resource consumption (energy, land, water, materials), environmental loadings (airborne emissions, solid waste, liquid waste) and improvement in indoor environmental quality (air, thermal, visual and acoustic quality) |
| Kibert [35] | The creation and responsible management of a healthy built environment based on resource efficiency and ecological principles |

In general, there is a consensus that the breadth of the principle of sustainable building mirrors those of sustainable development, which is about synergistic relationships between economic, social and environmental aspects of sustainability. Each of these three pillars (and their related principles) is over-arched by a set of process-orientated principles, including:

1. the undertaking of assessments prior to the commencement of proposed activities assists in the integration of information relating to social, economic, biophysical and technical aspects of the decision making process;
2. the timeous involvement of key stakeholders in the decision making process [31];
3. the promotion of interdisciplinary and multi-stakeholder relations (between the public and private sectors, contractors, consultants, nongovernmental) should take place in a participatory, interactive and consensual manner;
4. the recognition of the complexity of the sustainability concept in order to make sure that alternative courses of action are compared. This is so that the project objectives and the stakeholders are satisfied with the final action implemented;
5. the use of a life cycle framework recognizes the need to consider all the principles of sustainable construction at each stage of a project's development (*i.e.*, from the planning to the decommissioning of projects);
6. the use of a system's approach acknowledges the interconnections between the economics and environment. A system's approach is also referred to as an integrated (design) process;
7. that care should be taken when faced with uncertainty;
8. compliance with relevant legislation and regulations;
9. the establishment of a voluntary commitment to continual improvement of (sustainable) performance;
10. the management of activities through the setting of targets, monitoring, evaluation, feedback and self-regulation of progress. This iterative process can be used to improve implementation in order to support a continuous learning process; and
11. the identification of synergies between the environment and development.

These principles will form a framework for achieving sustainable building that includes an environmental assessment during the planning and design stages of building projects, and the implementation of sustainable practices. It will be used to guide the process of construction at all levels and within all disciplines. From them, it is possible to extrapolate an endless series of project- or discipline-specific principles and guidelines, which can assure that decisions taken follow the road of sustainable development.

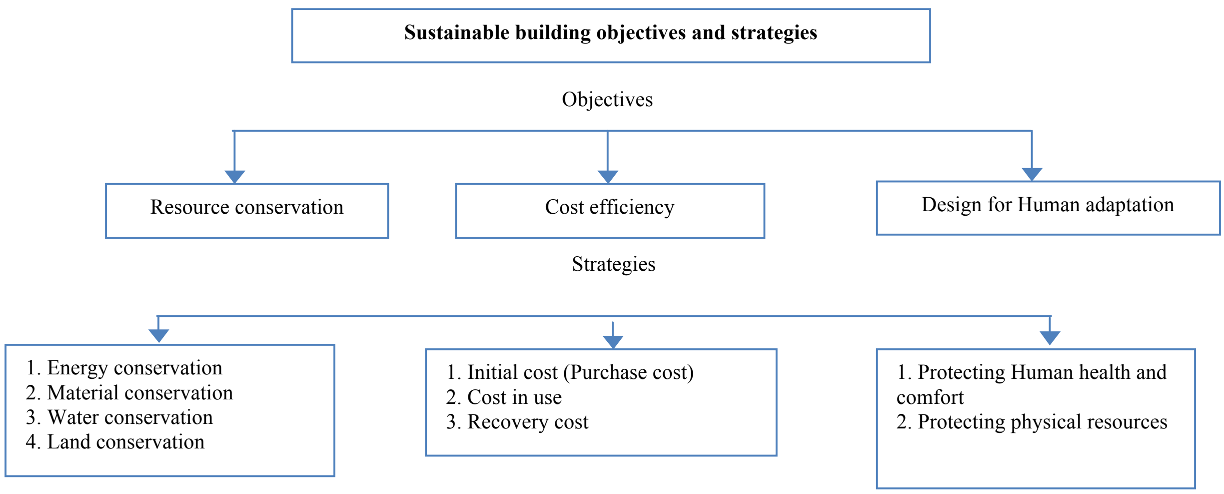
Building construction practitioners worldwide are beginning to appreciate sustainability and acknowledge the advantages of implementing sustainable principles in building projects. For example, the concept of sustainable building costs lower than conventional method and saves energy as demonstrated by Hydes and Creech [36]. This was further supported by Pettifer [37], who added that sustainable buildings will contribute positively to better quality of life, work efficiency and healthy work environment. Pettifer [37] explored the business benefits of sustainability and concluded that the benefits are diverse and potentially very significant.

## 3. Sustainable Implementation: A Framework of Strategies and Methods

In order to achieve a sustainable future in the building industry, Asif *et al*. [38] suggest adoption of multi-disciplinary approach covering a number of features such as: energy saving, improved use of materials, material waste minimization, pollution and emissions control *etc*. There are many ways in which the current nature of building activity can be controlled and improved to make it less environmentally damaging, without reducing the useful output of building activities. To create a competitive advantage using environment-friendly construction practices, the whole life-cycle of buildings should, therefore, be the context under which these practices are carried out. A review of literature has identified three general objectives which should shape the framework for implementing sustainable building design and construction (Figure 1), while keeping in mind the principles of sustainability issues (social, environmental and economic) identified previously. These objectives are:

1. Resource conservation
2. Cost efficiency and
3. Design for Human adaptation

**Figure 1.** Framework for implementing sustainability in building construction.

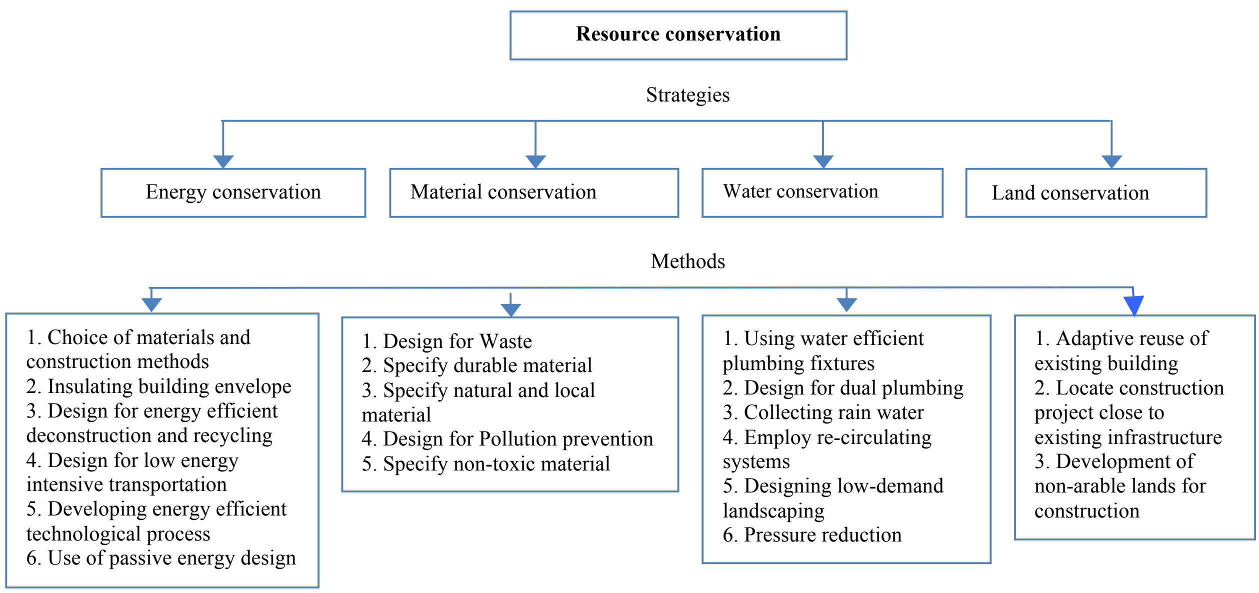


*3.1. Objective 1: Resource Conservation*

"Resource conservation" means achieving more with less. It is the management of the human use of natural resources to provide the maximum benefit to current generations while maintaining capacity to meet the needs of future generations [39]. The concept has become a major issue in debates about sustainable development. Halliday [1] observe that certain resources are becoming extremely rare and the use of remaining stocks should be treated cautiously. The author called for the substitution of rare material with less rare or renewable materials.

Bold statements about the need for radical improvements in the use of materials and energy resources have achieved recognition in policy circles. The argument is that productivity improvement is necessary to minimize impacts on the capacity of natural systems to assimilate waste materials and energy [1]. According to Graham [40], the building industry is a major consumer of natural resources, and therefore many of the initiatives pursued in order to create ecology sustaining buildings are focusing on increasing the efficiency of resource use. He stated that the ways in which these efficiencies are sought are varied. He cited examples ranging from the principles of solar passive design which aim to reduce the consumption of non-renewable resources, the consumption of energy production, life cycle design and design for construction. Methods for minimizing material wastage during building construction process and providing opportunities for recycling and reuse of building material also contribute to improving resource consumption efficiency. Calls to be resource efficient have been born from concern for increasing depletion of non-renewable natural resources. Since the non-renewable resources that play major role in a construction project are energy, water, material and land, the conservation of these non-renewable resources has vital importance for a sustainable future. Resource conservation yields specific design strategies and methods, as defined in Figure 2.

**Figure 2.** Strategies and Methods to achieve resource conservation.



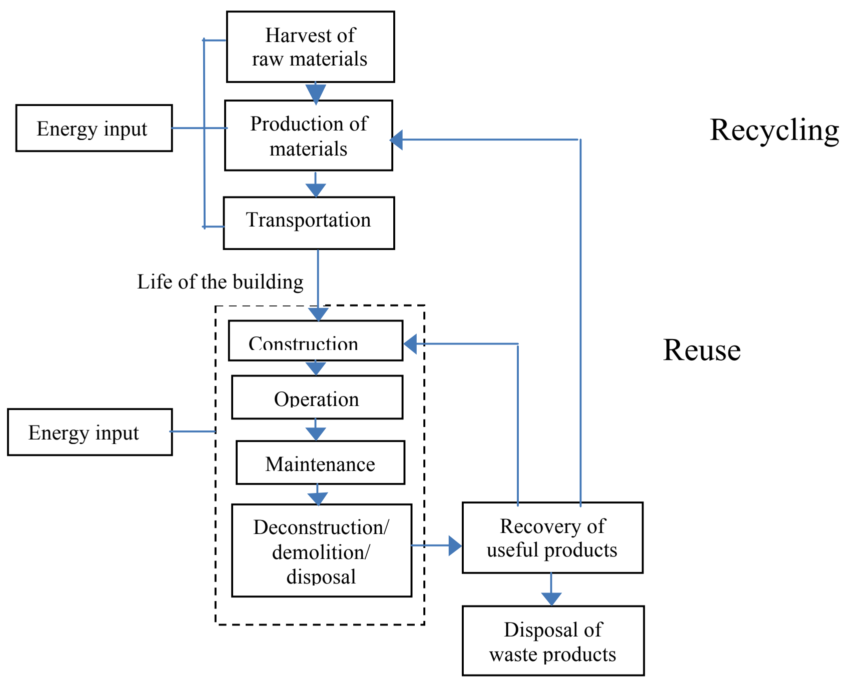
3.1.1. Energy Conservation

Energy use is one of the most important environmental issues and managing its use is inevitable in any functional society. Buildings are the dominant energy consumers.

Buildings consume energy and other resources at each stage of building project from design and construction through operation and final demolition [41]. According to Lenzen and Treloar [42], the kind and amount of energy use during the life cycle of a building material, right from the production process to handling of building materials after its end life can, for example, affect the flow of greenhouse gases (GHGs) to the atmosphere in different ways over different periods of time. Their consumption can be largely cut back through improving efficiency, which is an effective means to lessen greenhouse gas emissions and slow down depletion of nonrenewable energy resources [43]. With this realization, increasing more attention is being paid to the improved energy conservation in building sector over the years, partly because the sector harbours a considerable potential of primary energy saving and reduction of emissions, having a negative impact on the environment [44].

Energy use in a life cycle perspective includes energy needed for both operational and embodied energy. The operational energy requirements of a building can be considered as the energy that is used to maintain the environment inside that building [45]. Thormark [46] life cycle analysis of building shows that operational energy accounts for 85–95% of the total energy consumption and $CO_2$ emissions of a building which comes from occupancy through heating, cooling, ventilation, and hot water use. This will include energy from electricity, gas, and the burning of fuels such as oil or coal.

**Figure 3.** Stages of energy input during the life of a building.




As the energy needed for operation decreases, more attention has to be paid to the energy use for the material production, which is the embodied energy. The embodied energy of a building is the total energy required in the creation of a building, including the direct energy used in the construction and assembly process, and the indirect energy that is required to manufacture the materials and components of the building [47]. This indirect energy will include all energy required from the raw material extraction, through processing and manufacture, and will also include all energy used in transport during this process and the relevant portions of the energy embodied in the infrastructure of the factories and machinery of manufacturing, construction and transport. The energy life of a building can therefore be considered to be made up of numerous inputs of operational and embodied energy throughout a building life cycle as shown in Figure 3.

Therefore the main goal in energy conservation is to reduce the consumption of fossil fuels, as well as increasing the use of renewable energy sources. This could be achieved by the consideration of the following methods (Figure 2)

1. *Choices of materials and construction methods* are important to reduce energy consumption of a building through reduced solar heat gain or loss, thus reducing air-conditioning loads. Choosing materials with low embodied energy will help to reduce energy consumed through mining, processing, manufacturing and transporting the materials. For instance, aluminium has a very high embodied energy because of the large amount of electricity consumed to mine the raw material. True low energy building design will consider this important aspect and take a broader life cycle approach to energy assessment.
2. *Insulating the building envelope* is the most important of all energy conservation measures because it has the greatest impact on energy expenditure. A well designed and installed insulation can reduce the amount of heat lost through the building envelope by at least half [48]. Draughts and heat loss will be eliminated with an air-tightness strategy, where existing vents and chimneys will be blocked, floors and ceilings will be insulated, and walls will be coated with modified plaster. Heat recovery in high temperature areas such as kitchens and bathrooms, will achieve optimum energy efficiency through a mechanical ventilation unit that takes heat from these areas and uses it elsewhere in the house.
3. *Designing for energy efficient deconstruction and recycling of materials* cut energy consumption in manufacturing and save on natural resources. Buildings designed for deconstruction will include the disentanglement of systems, and reductions in chemically disparate binders, adhesives or coatings—or thermal/chemical/mechanical means to better separate constituent materials [49]. They will include a construction blueprint and also a deconstruction blueprint. They will have bar codes for materials so that the deconstruction contractor will have "handling" instructions for the material or component upon removal. These buildings will have self-supporting and self-stabilizing components, component accessibility designed in, and built- in tie-offs and connection points for workers and machinery. Most importantly, buildings that facilitate reuse and recycling will use non-hazardous materials, bio-based materials, high quality and highly recyclable materials. Design for deconstruction offers possibilities for the design of buildings that will close the loop of materials-use in building, and help make the transition towards a zero-energy building industry.
4. *Designing for low energy intensive transportation* reduces emissions causing pollution by affecting the amount of fuel used. The reduction of energy consumption in buildings has little impact on the national energy consumption if the urban and rural transportation systems waste

energy. An efficient community layout that places schools, shops, and other services close to homes and business, making it easy to get places without driving and offering attractive bicycle and walking paths, can greatly reduce vehicle miles travelled per household [50]. This would in turn reduce the amount of energy needed for transportation—while improving quality of life—even before any expenditures are made for vehicles. Therefore the design of low energy houses should be combined with an urban design that allows the use of public transportation and bicycles. If the cities maximize public transportation, the use of bicycles and minimize the use of private cars the result would be lower costs for energy and road construction, less traffic jams and less air pollution.

5. *Developing energy efficient technological processes* for construction, fitout and maintenance of buildings. A truly integrated approach to energy efficiency in building processes would need to be instigated by the project team right from the beginning to achieve the target energy consumption levels.
6. *Use of passive energy design* such as natural ventilation, landscaping by vegetation, use of water bodies for evaporation and cooling, orientation of building, *etc.* can help achieve thermal and visual comfort inside the building, so that there is significant reduction in energy consumption by conventional air conditioning and artificial lightning in a building. Architects and Designers can achieve energy efficiency in buildings by studying the macro and micro climate of the site, applying solar-passive and bioclimatic design feature and taking advantage of the natural resources on site.

#### 3.1.2. Materials Conservation

Extraction and consumption of natural resources as building materials or as raw materials for production of building materials and building materials production itself in implementing construction works has a direct impact on natural bio-diversity due to the fragmentation of natural areas and ecosystems caused by construction activities [51]. In particular, large amount of minerals resources are consumed in the built environment and most of these mineral resources are non-renewable. Therefore, it is important to reduce the use of non-renewable materials. According to Abeysundara *et al.* [52], this should be incorporated for consideration at the project initiative and design phases, where the selection of materials is very important and the choice should be based on the materials' environmental impacts. At the construction and deconstruction phases, various methods can also be used for reducing the impacts of materials consumption on the natural environment. The sub-section discusses some of the methods to be considered in achieve material efficiency in construction (Figure 2).

1. *Design for Waste Minimization.* The construction industry is one of the major waste generators, which causes several environmental, social and economic problems. Waste takes the form of spent or unwanted materials generated from construction and demolition processes. Prevention and reduction of waste in the construction of housing can save considerable amounts of non-renewable resources. An increasing body of scholarly work, notably that produced by [4,19,53–56] has demonstrated that the building designers have an important role to play in construction waste minimization and reduction. Waste minimization should be addressed as part of the project sustainability agenda throughout the design process by the application of the three key designing

out waste principles namely: Reducing and recovering construction waste; Reuse and Recycling and the storage and disposal of construction waste.

a. *Reducing and recovering construction waste:* According to Esin and Cosgun [57], the most effective measure of reducing the environmental impact of construction waste is by primarily preventing its generation and reducing it as much as possible. This will reduce reuse, recycling and disposal needs thus providing economic benefits. An analysis has shown that recovery reduces the amount of waste and Green House Gas (GHG) emissions, saves energy, and reduces the use of raw materials [58]. Recovery of useful energy and materials from wastes has also been emphasized as one of the most important environmentally friendly practices for achieving energy savings to alleviate the pressing energy situations [19,59].

*b. Reuse and Recycling:* Recycling products reduce general environmental impacts, particularly the use of resources and waste creation. The importance of alternatives (such as recycling and reuse) for re-entering construction materials and components in the production chain has been already presented in the literature [30,60–62]. The reuse of building materials is an alternative for the reduction of construction and demolition waste (CDW) when renovating and demolishing buildings, by performing building deconstruction, which enables the recover of building parts as functional components such as bricks, windows, tiles, differently from traditional demolitions in which parts are transformed back into raw materials to processing [63]. Designers should assess whether any existing buildings on site could be partly or completely refurbished to meet the project's needs; carrying out a pre-demolition audit of buildings that are being demolished to discover whether any materials or components can be reused. Designers should also assess whether deconstruction and flexibility can be considered, or is a priority.

c. *The storage and disposal of construction waste:* In situations where construction waste could not be prevented and recovered, they need to be stored in an appropriate manner and kept under control [57]. Non-hazardous construction debris and construction debris classified as special waste are landfilled in either municipal solid waste (MSW) landfills or in landfills that only accept construction debris. Around the world, decisions on the types of waste acceptable at landfills were entirely based on site-specific risk assessment. Licenses controlled the quantities and types of waste to be accepted and often, in the case of hazardous waste, specified maximum loading rates for particular wastes or components substances. Designers need to be aware and take into consideration policies and guidelines for material storage and disposal at the design stage of construction project.

2. *Specify durable materials.* Mora [64] defined durability as an indicator which informs of the extent to which a material maintains its original requirements over time. The sustainability of a building can be enhanced by increasing the durability of its materials [65], and a material, component or system may be considered durable when its useful service life (performance) is fairly comparable to the time required for related impacts on the environment to be absorbed by the ecosystem [64]. Materials with a longer life relative to other materials designed for the same purpose need to be replaced less often. This reduces the natural resources required for manufacturing and the amount of money spent on installation and the associated labor. The

greater the material durability, the lower the time and resources required to maintain it [66]. Durable materials that require less frequent replacement will require fewer raw materials and will produce less landfill waste over the building's lifetime.

3. *Specify Natural and Local Materials.* Natural materials are generally lower in embodied energy and toxicity than man-made materials [67]. They require less processing and are less damaging to the environment. Many, like wood, are theoretically renewable. When natural materials are incorporated into building products, the products become more sustainable [67]. The use of building material sourced locally can help lessen the environmental burdens, shortens transport distances, thus reducing air pollution produced by vehicles. Often, local materials are better suited to climatic conditions, and these purchases support area economies. For instance, the decorative use of marble quarried halfway around the world is not a sustainable choice. Steel, when required for structural strength and durability, is a justifiable use of a material that is generally manufactured some distance from the building site [68].
4. *Design for Pollution prevention.* Pollution prevention measures taken during the manufacturing and construction process can contribute significantly to environmental sustainability. Kibert [35], suggest selecting materials manufactured by environmentally responsible companies encourages their efforts at pollution prevention. Although these products may have an initially higher "off-the-shelf" price, choosing products that generate higher levels of pollution exploits the environment [68]. Pollution comes in form of air, water and soil. However, emissions to soil are hardly discussed in any LCA literature, and the data available are very limited. In the construction industry, soil pollution is mainly a problem at the construction site. It may also be a problem in the extraction of some minerals, when the waste is deposited, especially hazardous waste. This wastewater is often released directly into streams and can contain toxic substances. The means of transport is also important. Emissions from road, air and rail transport are a major cause of photochemical smog, of which the main components are carbon monoxide, nitrogen oxides, hydrocarbons and ozone released by the action of sunlight on organic compounds in the lower atmosphere [51]. Because of their bulk, and the large quantities involved, moving construction materials contributes very significantly to the total pollution emissions from transport. By becoming aware of which manufacturers use environmentally sustainable manufacturing methods, specifying their products, and avoiding goods produced through highly polluting methods, building designers can encourage the use and marketing of sustainable construction materials.
5. *Specify Non-Toxic or Less-Toxic Materials.* Non- or less-toxic materials are less hazardous to construction workers and building's occupants. Many materials adversely affect indoor air quality and expose occupants to health hazards. Some construction materials, such as adhesives, paints, sealants, cleaners, and other common products contain volatile organic compounds (VOCs) and emit dangerous fumes for only a short time during and after installation; others can contribute to air quality problems throughout a building's life [68]. By using building materials with lower or non-existent levels of toxic substances, environmental health problems can be avoided and the need for air scrubbers reduced.

3.1.3. Water Conservation

With the fast development of the global economy, depletion of water resources is becoming an environmental issue of the utmost concern worldwide. The United Nations World Water Development Report (WWDR) indicates that water for all our uses is becoming scarce and is leading to a water crisis [69]. The effects a sector can have on the environment are nowhere more apparent than in the building industry [70]. Building construction and its operations draw heavily on water from the environment. Growth in urban water use has caused a significant reduction of water tables and necessitating large projects that siphon supplies away from agriculture [71]. Water used to operate buildings is a significant component of national water consumption. However, this is not the only form of water consumed throughout a building's life cycle. Water is also consumed in the extraction, production, manufacturing, and delivery of materials and products to site, and the actual on-site construction process. McCormack *et al.,* [70] called this the "embodied" water.

Ilha *et al*., [10] observed that water conservation technologies and strategies are often the most overlooked aspects of a whole-building design strategy. However, the planning for various water uses within a building is increasingly becoming a high priority, in part because of the increasing recognition of the water savings that can be realized through the implementation of water saving initiatives. The literature reveals a number of strategies [10,70,72] that can be employed to reduce the amount of water consumed through a building life cycle. In general terms, these methods include:

1. *Utilizing water-efficient plumbing fixtures* such as ultra-low flow toilets and urinals, waterless urinals, low-flow and sensored sinks, low-flow showerheads, and water-efficient dishwashers and washing machines, to minimize wastewater.
2. *Design for dual plumbing* to use recycled water for toilet flushing or a gray water system that recovers rainwater or other non-potable water for site irrigation. Gray water is produced by activities such as hand washing, and does not need to be treated intensively as sewage. It can be recycled in a building to irrigate ornamental plants or flush toilets.
3. *Collecting rainwater using rainwater and grey water storage* for irrigation greatly reduces the consumption of treated water. Rainwater can also be used for household applications including drinking water. In fact, people in many regions of the world have traditionally relied on harvested rainwater for their water supply.
4. *Employ re-circulating systems* for centralized hot water distribution, which conserve water which is typically wasted by users while waiting for warm water to flow from a warm water faucet.
5. *Designing low-demand landscaping* using plants native to the local ecosystem also reduces water consumption on site, since these plants have been adapted to the local rainwater levels, thus eliminating additional watering [73]. The efficiency of water can also be improved by means of underground drip irrigation systems, which reduces water loss caused by evaporation of surface water during watering or after rain.
6. *Pressure Reduction*. Because flow rate is related to pressure, the maximum water flow from a fixture operating on a fixed setting can be reduced if the water pressure is reduced. For example, a reduction in pressure from 100 pounds per square inch to 50 psi at an outlet can result in a water flow reduction of about one-third [74].

#### 3.1.4. Land Conservation

Land is an important resource upon which the construction industry depends. Land use through urban expansion has been identified as a growing problem in both developed and developing worlds. Although more land may be reclaimed from the ocean, land reclamation on a large scale is undesirable since it could severely interfere with ecosystems. Soil erosion, groundwater contamination, acid rain and other industrial pollutants are damaging the health of plant communities, thereby intensifying the challenge and necessity to restore habitats. Sustainable design must develop a respect for the landscape and expend more effort understanding the interrelationships of soils, water, plant communities and associations, and habitats, as well as the impacts of human uses on them.

The impact of the construction industry on the environment and the expansion of urban areas show the importance of land as a vital indicator of sustainability with the potential to become an absolute indicator of sustainable construction [75]. Land can be conserve by adopting a policy of zero expansion of existing urban areas. This could be achieved by adaptive reuse of an existing building, thereby eliminating the need for new construction. In addition, placing sustainable building project within easy access of public transportation, medical facilities, shopping areas and recreational facilities, would prevent the expansion of built environment and occupation of agricultural and eco-sensitive areas. These methods would promote better use of urban land through a higher population density that would make better use of infrastructure services and transport systems. Another potential spin-off is the development of non-arable land for construction purposes, linked together by energy efficient mass transportation system.

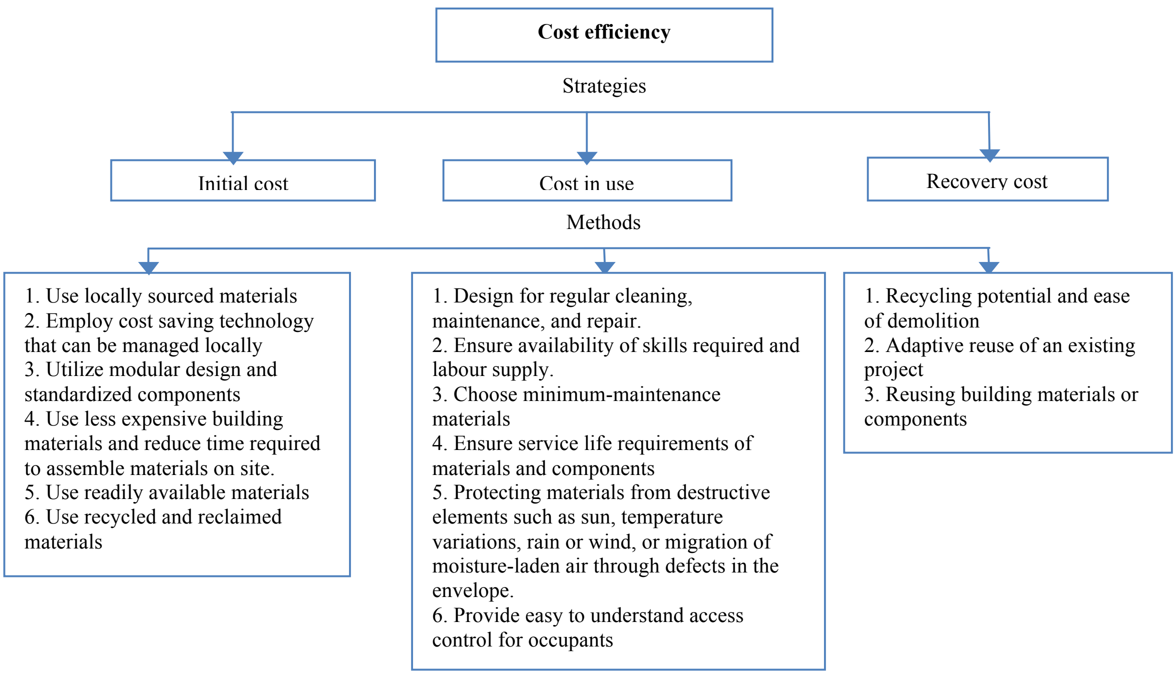
### *3.2. Objective 2: Cost Efficiency*

Construction clients are demanding assurance of their buildings' long-term economic performance and costs. In addition, the construction project supply chain of developers, suppliers, manufacturers, design and construction teams are under increasing pressure from clients to minimize total project cost and consider how much a building will cost over its life cycle and how successfully it will continue to meet occupier's requirements. Buildings represent a large and long-lasting investment in financial terms as well as in other resources [76]. Improvements of cost effectiveness of buildings is consequently of common interest for the owner, the user and society.

The concept of sustainability as applied to the construction of buildings is intended to promote the utmost efficiency and to reduce financial costs. There is considerable evidence to suggest that many organizations, in both the private and public sectors, make decisions about building related investment based on estimates of the initial construction cost, with little or no consideration for costs relating to operation and maintenance throughout the life of the building [77]. Design decisions require choice of construction structure, building materials and building installations which are often accompanied by errors in investment through an inadequate economic control of decisions [78]. Sharply rising energy costs have highlighted the opportunity for overall savings in the life of a building that can be achieved by investing in more energy efficient solutions initially. Savings on other operating and maintenance costs can also be considered, e.g., using building finishes that do not need frequent re-painting. A building's economic operation should be considered throughout the construction stage and also in terms of its maintenance and conservation throughout its useful life. In order to ensure that these objectives are achieved, the concept of life-cycle costing analysis (LCCA) will play significant roles in the economics of a building project. Life cycle cost analysis (LCCA) is an economic assessment approach that is able to predict the costs of a building from its operation, maintenance, and replacement until the end of its life-time [79].

The effective implementation of life-cycle costing involves utilizing a thoughtful, comprehensive design along with construction practices with selected environmental considerations. Life cycle cost (LCC) is therefore an important tool for achieving cost efficiency in construction projects. This paper has identified three principal life cycles cost to be considered at the outset of a construction project. The initial cost, the cost in use and the recovery cost (Figure 4).

**Figure 4.** Strategies and Methods to achieve cost efficiency.




### 3.2.1. Initial Cost

Also referred to as the acquisition cost or the development cost, the initial cost covers the entire cost of creating, or remodelling, the building [80], such as cost of land/building acquisition costs, professional consultants fee, the cost of the materials that compromise the completed building, and the cost of putting it all together. When planning the acquisition of a major asset, Emmitt and Yeomans [80] observed that organizations spend considerable time and effort in making an economic evaluation of the initial cost. For many clients, this is their primary and often only concern. Cost reductions may be possible by selecting less expensive building materials and reducing the amount of time required to assemble them on site, but this assumes that these costs can be discovered. Other methods associated with initial cost reduction in building include the following:

1. *The design should optimize the use of locally-available materials*. In most cases, locally manufactured products are cheaper than their imported counterparts since their transport costs are not as huge and they do not come with import duty.
2. *Use of cost saving construction technology* such as the use of masonry stone for building foundation instead of reinforced concrete saves a lot of cost. This method is only suitable for low-rise buildings such as bungalows. For high-rise structures, careful structural design can be utilized so as to have the most optimum foundation design type to ensure less material is excavated.
3. *Identify opportunities to minimize initial construction costs, through use of modular designs and standardized components* where these are compatible with high quality, distinctive architecture that is appropriate to its context. For instance, a standardized plan with uniform office sizes provides an organizational framework that can be reconfigured as required, even the company changes. The design should also support technological changes [81].
4. *Use common, readily available components*, where appropriate, to minimize replacement costs and stocking of custom components. Project components that cannot be easily repaired or replaced should be sufficiently durable to minimize expensive replacement and retrofitting.
5. *Using recycled and reclaimed materials.* On site reuse and reprocessing of construction, demolition and excavation materials; and importing recovered and recycled materials in the place of more costly primary material can significantly reduce overall project cost. For examples, using products with a high recycled content, such as recycled asphalt or cement replacement in concrete products can save project cost by at least 3% [82] without significant investment outlay.

### 3.2.2. Cost in Use

Otherwise known as the running cost or operation cost, the cost in use is set by the decisions made at the briefing stage and the subsequent decisions made during the design and assembly phases [80]. It also involves regularly scheduled adjustments and inspection to protect a building so that it goes on to supply the same comfort and appliances-resources and the cost of parts to perform repairs [83]. Furthermore, decoration, fabric of building (*i.e.*, roof, external walls), services (*i.e.*, heating and ventilation) also took place at this level.

For many years, running costs were only given superficial attention at the design stage, although this has changed with the use of life cycle costing techniques that help to highlight the link between design decisions and costs in use. Materials and components with long service lives do cost more than those not expected to last so long and designing to reduce both maintenance and running costs may result in an increase in the initial cost [80]. However, over the longer term, say 15 years, it might cost the building owner less than the solution with lower initial cost. Cost reduction in the use of building can achieve by taking into consideration the following.

1. *Taking adequate measures within the design of key building elements* to provide dedicated and generous space for regular cleaning, maintenance, and repair to the central or major elements of the HVAC system and ensure that access points are readily identified and locatable.

2. *Ensuring that the skills required are within the competence of available labour supply*. Absence of abundant labour with building facilities maintenance skills can result in increased maintenance costs. Where local skills are available for example bricklayers, structures should be designed to make maximum use of such skills. A project can specify brick manholes in favour of precast concrete ones in order to harness available skills.
3. *Choosing minimum-maintenance materials*. Where possible, select building materials that require little maintenance (painting, retreatment, waterproofing, *etc*.). For example Wood plastic composite (WPC) low-maintenance advantages over wood continue to drive growth in wood-replacement applications [84].
4. *Adopting an appropriate process during the design stage to protect materials from destructive elements* such as sun, temperature variations, rain or wind, and isolate critical sections of the building or systems from damage that may occur from flooding or storm damage.
5. *While fully meeting the operational requirements of the building, provide easy-to-understand and easy-to-use building control systems* for occupants and building operators to ensure effective operation of energy efficient technologies and components. If a simple system can achieve the objective, then a complicated one should be avoided.

#### 3.2.3. Recovery Cost

There is a third cost that is rarely considered—the cost of demolition and material recovery [80]. This is partly because the client may well have sold the building long before the building is recycled and partly because such costs are traditionally associated with the initial cost of the future development. Again this may be of little concern to the current client who is looking for short term gain with minimal outlay. However, if we are to take environmental issues seriously, then the following methods should be implemented to reduce or eliminate recovery cost.

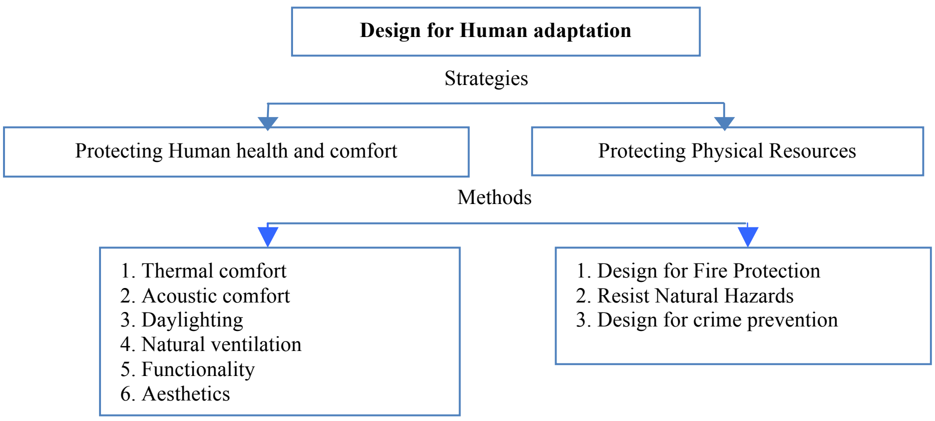
1. *Recycling potential and ease of demolition* should be considered during the design phases and costed into the development budget. It enhances the sustainability of construction industry. Waste means new resources for new constructions. In most cases, making products by recycling demolition wastes creates less air pollution and water pollution than making new products. Recycling also creates jobs as well as saving valuable resources, thus protecting the natural environment.
2. *The adaptive reuse of an existing project* significantly reduces waste and conserves the energy used for material manufacturing and construction. The energy embodied in the construction of a building and the production of materials will be wasted if the existing resource is not properly utilized. This approach may also preserve cultural heritage by keeping a historical building in use and maintained.
3. *Reusing building materials or components* is a way of minimizing waste production, if an old building is not completely available for reusing. In such cases, it may be preferred to renovate and reuse individual components, such as windows, doors and interior fixtures.

Attention to the life cycle cost of building project in terms of both design and choice of materials will minimize the overall costs for owner and users. It is important to determine how long the building is designed to last and whether it is likely that functional requirements will change in this time. Moreover, if it is likely that re-sale value will be enhanced by ability to adapt to new uses, then appropriate design can substantially reduce the costs of adapting to new uses. Thus, increasing cost effectiveness of a building is a critical strategy for creating sustainable building.

### *3.3. Objective 3: Design for Human Adaptation*

One of the main purposes of a sustainable building is to provide healthy and comfortable environments for human activities. A building must accommodate the activities it is built for and provide floor-space, room volume, shelter, light and amenities for working, living, learning, curing, processing *etc*. Furthermore, the building must supply a healthy and comfortable indoor climate to the people using it. In meeting these basic requirements, the building should not cause harm to its occupants or the environment and must, for example, be structurally stable and fire safe. Sustainable development requires that the building does not cause unnecessary load or risk to the environment, for example in the form of energy use. To promote and enhance human adaptation the following two design methods should be considered (Figure 5).

**Figure 5.** Strategies and Methods to achieve human adaptation.




#### 3.3.1. Protecting Health and Comfort

Well-being (health and comfort) is an important aspect determining the quality of life of an occupant. In a modern society, where individuals spend more than 90% of their time indoors—and more than 70% of their time indoors at home [72,85], an essential role of architecture is to provide occupants' health, physiological comfort, physiological satisfaction and productivity. The concept of health is significant for identifying the concept of a "sustainable building" in terms of building performances (*i.e.*, indoor air quality, thermal comfort, lighting quality and acoustics). A sustainable industry must balance human needs with the carrying capacity of natural and cultural environments. A healthy building is free of hazardous material (e.g., lead and asbestos) and capable of fostering health and comfort of the occupants during its entire life cycle, supporting social needs and enhancing productivity. A healthy building recognizes that human health needs, and comfort, are priorities.

Many building designers have been preoccupied with style and form-making, disregarding environmental quality and human satisfaction in and around the built environment. According to

Sev [72], a product may save energy and perform well; however, if it does not positively affect the occupants' comfort and enhance productivity, it is not a sustainable product. A review of the literature identified the following (but not limited to) methods as a necessity in enhancing the coexistence between the environment, buildings and their occupants (Figure 5).

1. *Thermal comfort* is a key to occupant's satisfaction and productivity. Maintaining thermal comfort for occupants of buildings or other enclosures should be one of the important goals of every building designer. The environmental parameters which constitute the thermal environment are: Temperature (air, radiant, surface), humidity, air velocity and the personal parameters: clothing together with activity level. Building envelope considerations, such as reflective roofing, low-E windows, window tinting and solar shading are some of the tools that enable designers to optimize thermal comfort as well as improving energy efficiency. Siting the building according to seasonal heat gain and use is another key to thermal comfort, as is landscaping.
2. *The acoustical environment* of a workspace is typically given little or no attention during project planning and design. Acoustic comfort must be achieved by controlling sources of noise from mechanical and electrical equipment and from sources exterior to the building. Proper selection of windows, wall insulation and wall framing, and materials are essential to reducing noise from outside. Some sound insulating materials, such as acoustic ceiling tiles and straw-bale construction, can offer the advantages of recycling and using natural materials [72,86]. Hard versus absorbent surfaces also have a major impact on noise level inside a space. Noise elimination, control or isolation from HVAC equipment should also be addressed through acoustic zoning, equipment selection, construction and appropriately designed ducts, piping and electrical systems. There may be opportunities to meet project sustainability goals in conjunction with good acoustical design if they are considered early in the project development phase.
3. *Daylighting* involves designing buildings for optimum use of natural light and provides numerous benefits over artificial lighting. Generally it is understood to be beneficial both to health and well-being. Maximising good daylight in housing is therefore an important consideration. Good daylight means levels of daylight which are sufficient to see properly without glare or excessive contrast. Too much direct sun can actually cause discomfort and ill health, particularly with highly reflective surfaces.
4. *Natural ventilation* is the process of replacing air in any space to provide high indoor quality without the use of mechanical means. Ventilation conditions inside a space have a direct influence on the health, comfort and well-being of the occupants. Natural ventilation has become an important strategy in building designs. It can be used to supply outside air, reduce odours and pollutants, and remove heat from spaces, people and mass. Designing for natural ventilation also has potential to reduce construction and operational costs associated with the purchase and use of mechanical equipment, and the increased productivity of building occupants due to improvements in the indoor environment and connection with the outdoors. The climate suitability, window orientation and operable windows are the key factors for natural ventilation. Examples include providing cross-ventilation to make use of wind chimneys to induce stack ventilation, and using water evaporation systems in hot dry climates to induce air

movement. Being able to open a window, to sit in the sun or shade and to have contact with nature appears to be key characteristics in sustainable building design [87].

5. *Building functionality* should be planned to enable the smooth operation of the activity for which the building is designed. The capacity of a building to absorb future functions should be studied at the outset, in the event of an expansion, and to reduce the additional material and building waste disposal costs. The consideration of low-maintenance and durable constructive elements is of special importance, even where it may not be strictly necessary in the long term.
6. *Building aesthetics* is a further value to bear in mind, with a view to contributing to psychological comfort in the work and living environment. This aspect of psychological comfort could mean pleasing architecture, visual interest, art on the walls, or natural elements, such as a fountain, plants, or an aquarium. The effect of beauty may be hard to measure, but it emphasizes the aesthetical requirement as a sustainable aspect.

3.3.2. Protecting Physical Resources

Protecting physical resources is one of the most important principles of sustainable design and construction. Consideration must be given to design that incorporate building resilience against natural and man-made disasters such as fire incident, earthquake, flooding and crime attack. Hazard mitigation planning is the process of determining how to reduce or eliminate the loss of life and property damage and the methods to achieve these tasks are as follows (Figure 5).

1. *Plan for Fire Protection*. The most crucial aspect of a building's safety involves a systems approach that enables the designer to analyse all of the building's components as a total building fire safety system package. As buildings become more complex and architects push the design envelope ever further, it is vital to consider fire safety implications of new buildings or other construction or refurbishment projects at the concept design stage. An important precondition is that its fire safety facilities enable independent and adequate fire response performances by the building's occupants. The consideration of Fire Stopping and Passive Fire Protection measures are vital to the stability and integrity of a building or structure in case of fire [88]. A fire strategy will only achieve maximum effectiveness if the passive fire protection measures, such as insulated fire-resisting partitions, cavity barriers, specialist fire-stopping of gaps in structure with their proven fire performance properties, are built into the fabric of a building. Passive fire protection not only maintains the stability of a building's structure during fire, they provide stability and separate the building into areas of manageable risk (Fire Compartments). These are designed to keeps escape routes safe and helps isolate and limit fire, heat, and smoke allowing the occupants to escape and the fire fighters to do their job safely. Such protection is either provided by the materials from which the buildings was constructed or, have been added to reinstate or establish the fire integrity.
2. *Resist Natural Hazards*. Recent natural and human-induced events have highlighted the fragility and vulnerability of the built environment to disasters. In most of these cases, occupants are left to pay for the recovery effort, including repairing damaged buildings and infrastructure, from the impacts of hurricanes, floods, earthquakes, tornados, blizzards, and other natural disasters. Hazard resistance methods should be an important project design requirement in the same way

that environmental considerations are now integral parts of project documents. For example, flood mitigation techniques include elevating buildings above floor levels in flood prone areas; making buildings watertight to prevent water entry, incorporation of levees and floodwalls into site design to keep water away from the building. Adding retrofitting techniques such as ferro-cement veneer, vertical corner reinforcement embedded in mortar and introducing tie beams and adding buttress to brick masonry and mud-wall housing will also go a long way in protecting against natural hazards. For details of other hazards preventions methods, the reader is referred to Whole Building Design Guide by the National Institute of Building Sciences.

3. *Crime prevention* through architectural Design has emerged worldwide as one of the most promising and currently effective approaches to reducing opportunities for crime. The basic tenet of crime prevention through design in building is that proper design and effective use of the built environment can reduce the fear and incidence of crime and thereby improve the overall quality of life. Effective secure building design involves implementing countermeasures to deter, detect, delay, and respond to attacks from human aggressors. It also provides for mitigating measures to limit hazards to prevent catastrophic damage and provide resiliency should an attack occur. Crime prevention methods emphasize the following three design approaches: natural access control; natural surveillance; and territorial behaviour [89]. Access control uses doors, shrubs, fences, gates, and other physical design elements to discourage access to an area by all but its intended users. Surveillance is achieved by placing windows in locations that allow intended users to see or be seen while ensuring that intruders will be observed as well. Surveillance is enhanced by providing adequate lighting and landscaping that allow for unobstructed views. Finally, territory is defined by sidewalks, landscaping, porches, and other elements that establish the boundaries between public and private areas. These three methods work together to create an environment in which people feel safe to live, work, travel, or visit.

## 4. Conclusions

Sustainable building is considered as a way for the building industry to move towards protecting the environment. The promotion of sustainable building practices is to pursue a balance among economic, social, and environmental performance in implementing construction projects. If we accept this, the link between sustainable development and construction becomes clear; construction is of high economic significance and has strong environmental and social impacts. With the growing awareness on environmental protection, this issue has gained wider attention from construction practitioners worldwide. Implementing sustainable building construction practices has been advocated as a way forward in fostering economic advancement in the building industry while minimizing impact on the environment. In order to reduce these detrimental impacts of construction on the environment and to achieve sustainability in the industry, three principles emerge: resource efficiency, cost efficiency and design for human adaptation. They form framework for integrating sustainability principles into construction projects right from the conceptual stage.

The framework has considerable potential to accelerate the understanding and implementation of sustainability in building construction. It provides a brief overview of sustainability principles, strategies and methods, and emphasizes the need for an integrated and holistic approach for implementing sustainability in building projects. It is intended to provide a general framework for improving the quality and comparability of methods for assessing the environmental performance of buildings. It identifies and describes issues to be taken into account when using methods for the assessment of environmental performance for new or existing building properties in the design, construction, operation, refurbishment and deconstruction stages. It is not an assessment system in itself but is intended to be used in conjunction with, and complimentary to existing assessment systems such as BREEAM, BEES, LEED, *etc*.

The sustainability requirements are to a greater or lesser extent interrelated. The challenge for designers is to bring together these different sustainability requirements in innovative ways. The new design approach must recognize the impacts of every design choice on the natural and cultural resources of the local, regional and global environments. These sustainability requirements will be applicable throughout the different stages of the building life cycle, from its design, during its useful life, up until management of the building waste in the demolition stage. This framework lays the groundwork for the development of a decision support tool to help improve the decision making process in implementing sustainability in building projects. The full decision support tool will be described in the model currently being developed for use in the UK building industry.

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